This is an advance copy of a paper to be presented at the Sixty-Third Annual Meeting of the American Society for Testing Materials (1916 Race St., Philadelphia 3, Pa.) to be held in Atlantic City, N. J., June 26-July 1. This advance copy is primarily to stimulate discussion. Discussion is invited and may be transmitted to the Executive Secretary. The paper is subject to modification and is not to be published as a whole or in part pending its release by the Society through the Executive Secretary.

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COMPARISON OF NUCLEAR AND SAND CONE METHODS OF DENSITY AND MOISTURE DETERMINATIONS FOR FOUR NEW YORK STATE SOILS

By

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INTRODUCTION

This report summarizes and compares the results of density and moisture content measurements made on compacted embankments, using the nuclear or radiation method and the sand cone method. The latter method has been utilized as a standard for such measurements by the Bureau of Soil Mechanics, New York State Department of Public Works, for many years. The tests were performed on three highway projects under construction, and involved four basic soil types. The tests were performed on August 24 and 25, 1959.

The "d/M Gauge", manufactured by the Nuclear-Chicago Corporation, was utilized for the Nuclear method portions of the test. The instrument was operated by and the readings interpreted by Mr. Jack Templeman of that firm. The density and moisture content determinations, using the sand cone method, were performed by personnel of the Bureau of Soil Mechanics under the supervision of the author.

The testing described in the following report represents the preliminary phases of a program investigating the suitability and adaptability of the nuclear method for embankment compaction control under the various conditions prevailing in New York State.

Since the following tests represent the preliminary phase of this program, no conclusions are included in this report. The results obtained from the tests are presented for information purposes to indicate the trend of the program and as a guide for further investigation.

DESCRIPTION OF THE TWO METHODS

"d/M Gauge" - Moisture and Density Surface Probes

The "d/M Gauge" used consisted of a Model P21 Surface Moisture Probe, a Model P22 Surface Density Probe and a Model P2800 Scaler. The approximate time required for a complete moisture or density measurement was two minutes. The probe was placed on the surface of the layer to be tested, the timer set to the desired time interval and then the scaler read for the count. This "count" was then located on a calibration chart, from which the moisture content or wet density was obtained, the value being indicated as "pounds per cubic foot."

The P21 Moisture Probe measures a semispherical volume of material, the depth of which varies from approximately five to fifteen inches, while the P22 Density Probe measures to a depth of approximately three to eight inches.

The principle of operation of the d/M Gauge equipment is based on the degree that radioactivity is "scattered" when placed in contact with materials of different moisture content or density. After the equipment has been calibrated for various moistures and densities, measurements of the resulting scatter provides

a method for determining moisture content or density of the soil layer being tested.

The P21 Surface Moisture Probe contains a radioactive radium-Beryllium source of fast neutrons and the P22 Surface Density Probe contains a cesium - 137 gamma ray source. Each probe contains a detector system, which is sensitive to radioactive "scatter." The count of impulses received from the probe is registered on the P2800 Scaler glow tube registering system; this count is then located on the calibration chart and the moisture content in pounds per cubic foot, or wet density, also in pounds per cubic foot, read directly from the chart. The dry density is obtained by subtracting the moisture measurements from the density measurements. Percent of moisture content by dry weight is obtained by dividing the dry density into the pounds per cubic foot of water.

Bureau of Soil Mechanics - Field Compaction Control Density Test

The field compaction test of the Bureau of Soil Mechanics, New York State Department of Public Works, utilizes a calibrated Sand Cone apparatus for determination of density. The test procedure consists of measuring the actual wet density of the compacted material in the field by removing a sample of soil from the layer and determining the actual volume of the hole from which the soil was removed. All of the soil removed from the hole is retained and, knowing the weight of the soil and the volume the soil occupied in the test hole, the wet density is computed.

The moisture content of the soil is determined by taking a sample of the wet soil, drying it to constant weight in a laboratory oven at 110° Centigrade, and then obtaining the ratio of the water in the sample to the dry weight of soil, expressed as a percentage. The dry density is determined by correcting the wet density for the moisture content of the sample.

The Bureau's sand cone method is in conformance with ASTM "Suggested Method of Test for Determining Density of Soil in Place by the Sand-Cone Method", which was submitted by Section B of Subcommittee R-8.

TEST PROCEDURE

In place field density and moisture measurements were first made, using the "d/M Gauge" on several carefully levelled locations at each site. Sand cone measurements were made at each identical spot immediately after the "d/M Gauge" was moved to the next location. The soil extracted from each sand cone hole was sealed in air-tight jars for moisture determination at the laboratory.

Tests were performed on the following projects:

	Project	Soil Type
(1)	Interstate Route 502 - Glens Falls By-Pass, FISH 58-19 (Saratoga County)	Brown Sand, trace of silt
(2)	Amsterdam Arterial - FAC 58-16 (Montgomery County)	Brown Silt and Clay
(3)	Ballston Spa - Scotch Church - FARC 58-13 (Schenectady County)	Brown Sand and Gravel, some silt trace of clay
(4)	Ballston Spa - Scotch Church - FARC 58-13 (Schenectady County)	Brown Glacial Till

TEST RESULTS

Materials representing some predominate soil types utilized in highway construction in New York State, were selected to obtain a general comparison and evaluation of the two methods. The characteristics of the four soil types selected are shown on Table I. Figures I and 2 show the Laboratory Compaction Curves at Standard A.A.S.H.O. Effort, prepared from composite field samples representing each of the four soil types. Figure 3 indicates the grain size characteristics of a composite sample of each of the four soils upon which the tests were run.

The results of the wet density and moisture measurements made, using the two methods, on the four soils are listed on Table II. Also listed are the dry densities and percentages of maximum dry densities, based on the measured wet densities and moisture contents.

Figures 4 through 7 graphically illustrate, for each of the soils, the variation of the results obtained from the two test methods. On the left side of each of the figures, the densities obtained from the nuclear method are plotted in relation to the densities obtained from the sand cone method. This plot shows the difference in percent that the result of each nuclear method test varied from the result of the sand cone test at the same location. The percent difference is computed, using the sand cone result as the base. If the results obtained from the two methods were identical at the same location, that point would fall on the "zero percent difference base line." Points to the left and

above the zero line indicate that the density obtained by the nuclear method was higher than that obtained by the sand cone. Points to the right and below the zero line indicate that the density value obtained by the nuclear method was lower than that obtained by the sand cone method. Percent difference lines in intervals of five percent are drawn on the plots to indicate the percent variation.

On the right side of each figure (4 through 7), the moisture contents obtained from the two methods are plotted in a manner similar to that described above for density. Here again, the moisture contents obtained from the laboratory determinations are used as the base, with the nuclear results indicated at various differences from this base. The percent differences shown on each moisture content plot are considerably greater than the percentages prevailing on the density plots. Since the moisture contents expressed as percentages of dry densities are small, large percentage differences result even though actual differences are small.

The method used in Figures 4 through 7 to graphically compare the results obtained from the two methods, wherein the sand cone values are used as the base or datum and the nuclear method values plotted as differing from this base, is not intended to infer that the sand cone method is more accurate than the nuclear method. Obviously, any method of measurement has errors and tolerances. The sand cone method is used as the base

or datum because this method has been universally used for many years by the New York State Department of Public Works and accepted by its contractors. Results obtained from new methods must be compared to those obtained from accepted methods for evaluation purposes.

FURTHER INVESTIGATIONS

Obviously, the nuclear method of density and moisture content measurement presents considerable possibilities for an extremely rapid and convenient method of embankment compaction control. However, further investigation is necessary in order to ascertain how this method can be effectively and economically employed by the New York State Department of Public Works for compaction control on projects under construction.

The density and moisture content differences illustrated in Figures 4 through 7 are based on a single nuclear calibration curve for density and one for moisture, regardless of the soil type. Although a limited number of tests were performed in this phase of the program, described above, to draw any definite conclusions, Figures 4 through 7 indicate the possibility that several curves for several basic soil types may be necessary. Further investigation is, therefore, necessary to ascertain whether several calibration curves will be needed for compaction control on projects that involve the many different soil types prevailing in glaciated areas.

Further investigation is also necessary for another aspect of compaction control by nuclear methods in New York. Because extreme variations in soils are possible on a single project, the New York State Department of Public Works has used the "family of curves" method for construction compaction control for many years. This procedure requires that a "one point" Proctor test be run on the material extracted from each field density measurement hole in order to establish the position of the compactive effort - moisture - density curve in the family, which is applicable for the general soil type being utilized for construction at that location. This is necessary in order to indicate the percent of maximum dry density being obtained, in accordance with New York State Specifications. In the first phase of these investigations, no method of establishing the position of the actual soil being placed within the "family of curves" has been evolved for the nuclear method.

Since a nuclear method for density and moisture measurements presents potential advantages in speed and convenience over existing established methods, it is intended that the Bureau of Soil Mechanics will continue to investigate the economy and feasibility of the nuclear methods to ascertain the optimum degree of application of such methods to the work of the New York State Department of Public Works.

SM-105A1-R1

STATE OF NEW YORK · DEPARTMENT OF PUBLIC WORKS
DIVISION OF CONSTRUCTION · BUREAU OF SOIL MECHANICS

SUMMARY OF LABORATORY TEST RESULTS

SHEET NO. 1 OF 1
DATE FEB. 15, 1960
TABLE I

PROJECT d/M Gauge vs. Sand Cone Testing DISTRICT ____ COUNTY ____ CONTRACT NO. ____

LABORATORY NO.	HOLE NO.	SAMPLE NO.	DEPTH-FT.	STATION	OFFSET	NAT. MOISTURE - %	OPT. MOISTURE - %	MAX. DRY DENSITY LBS. PER CU. FT.	SP. GR. +3/4"	SP. GR. -3/4"	LIMIT TESTS: LIQUID LIMIT - %	LIMIT TESTS: PLASTIC INDEX	SEIVE ANALYSIS – MECHANICAL ANALYSIS – PERCENT FINER THAN: 4"	2 1/2"	1"	3/4"	3/8"	1/4"	NO. 4	NO. 10	NO. 40	NO. 60	NO. 100	NO. 200	HYD. ANAL: -.02 MM	-.002 MM
Glens Falls - By Pass							14.0	110.5	-	2.80	-	N.P.								100	87.9	62.2	30.0	5.8	-	
Amsterdam Arterial							23.5	99.7	-	2.71	50.4	24.3		100	97.1		96.6	96.3	96.3	95.8	93.1	92.0	91.0	89.3	69.2	44.9
Ballston Spa - Scotch Church							7.5	132.4	2.59	2.74	24.6	7.0	100	95.1	83.9	80.0	75.1	65.1	61.4	51.6	30.2	25.3	22.9	20.4	10.4	4.5
Ballston Spa - Scotch Church							12.5	118.5	2.59	2.73	23.4	4.9		100		96.3	93.3	91.9	90.9	86.7	74.5	65.5	57.3	49.5	23.2	12.8

STATE OF NEW YORK
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TABLE 2
OCTOBER 8, 1959

D/M GAUGE - VS - SAND CONE
MOISTURE - DENSITY COMPARATIVE RELATIONSHIPS

Project Information	Test No.	Depth In.	Location	Soil Description	Wet Density - Lbs/Cu. Ft.		Percent Moisture		Dry Density - Lbs/Cu. Ft.		Percent of Maximum Dry Density (AASHO Standard Test)	
					D/M Gauge Avg. 4 Tests	BSM Sand Cone	D/M Gauge	BSM	D/M Gauge	BSM Sand Cone	D/M Gauge	BSM Sand Cone
Glens Falls By Pass FISH 56-19 Saratoga County Max. Dry Density 110.5# Opt. M.C. 14.0%	1	0-6"	C24+10 50' RT	Brown Sand, trace silt	121.0	118.9	3.9	3.1	116.4	114.5	105.4	103.6
	2	"	C24+25 50' RT	" " " "	118.8	114.6	4.2	3.8	112.0	110.4	101.3	100.0
	3	"	C24+50 50' RT	" " " "	124.2	119.1	5.2	6.0	116.0	112.4	106.9	101.3
	4	"	C24+50 25' RT	" " " "	118.7	119.0	7.6	9.0	110.1	109.2	99.7	99.0
	5	"	C24+25 25' RT	" " " "	119.0	115.3	7.2	7.8	111.0	107.0	100.5	96.9
	[illegible]	"	C24+10 25' RT	" " " "	120.1	118.3	7.6	9.5	111.6	108.0	101.1	97.6
	[illegible]	10"-16"	C24+10 22' RT	" " " "	120.4	118.1	7.0	6.8	112.5	110.6	102.0	100.1
	[illegible]	"	C24+50 22' RT	" " " "	119.2	119.3	4.7	3.5	113.9	115.3	103.0	104.3
	[illegible]	"	C24+25 50' RT	" " " "	118.7	117.0	4.5	4.3	113.6	112.2	102.8	101.8
Amsterdam Arterial FAC 56-16 Montgomery County Max. Dry Density 99.7# Opt. M.C. 23.5%	1	0-6"	Vicinity of Abutment	Brown Silt & Clay	125.1	122.8	17.9	26.5	106.1	97.1	106.5	97.4
	2	"	" " "	" " " "	128.0	126.8	16.9	22.7	109.5	103.2	110.0	103.5
	3	"	" " "	" " " "	123.2	121.3	18.1	25.9	104.2	96.5	104.8	96.9
	4	"	" " "	" " " "	123.5	124.4	17.4	23.9	105.3	99.8	105.8	100.1
	5	"	" " "	" " " "	122.6	-	18.3	25.1	103.6	-	104.0	-
	6	"	" " "	" " " "	122.0	-	17.9	23.2	103.5	-	104.0	-
Ballston Spa - Scotch Church FARC 56-131 Schenectady County Max. Dry Density 132.4# Opt. M.C. 7.5%	1	0-6"	230+75 15' RT	Brown Sand & Gravel, some silt, trace clay	128.9	131.9	6.6	7.2	120.9	123.0	91.4	93.0
	2	"	230+50 15' RT	" " " "	126.0	126.8	7.4	7.8	117.4	117.6	88.6	88.7
	3	"	230+50 5' RT	" " " "	133.6	134.4	6.8	8.0	125.1	124.4	94.5	93.5
	4	"	230+25 20' LT	" " " "	134.8	125.1	6.7	7.3	126.3	116.5	95.5	88.0
	5	"	230+50 20' LT	" " " "	135.0	135.1	5.5	6.3	131.7	127.1	99.5	96.0
	6	"	230+95 20' LT	" " " "	132.3	133.8	6.0	5.6	125.2	126.7	94.5	95.7
Ballston Spa - Scotch Church FARC 56-131 Schenectady County Max. Dry Density 116.5# Opt. M.C. 12.5%	7	0-6"	231+10 20' LT	Brown Till	116.1	120.9	10.1	9.7	105.4	110.4	89.0	93.2
	8	"	229+75 25' RT	" "	125.1	124.6	12.1	13.4	111.6	109.9	94.0	92.8
	9	"	230+00 25' RT	" "	122.4	125.9	10.1	11.3	111.1	113.1	93.8	95.5
	10	"	- -		127.1	125.1	10.0	11.7	115.6	112.0	97.5	94.5

FORM SN 39A

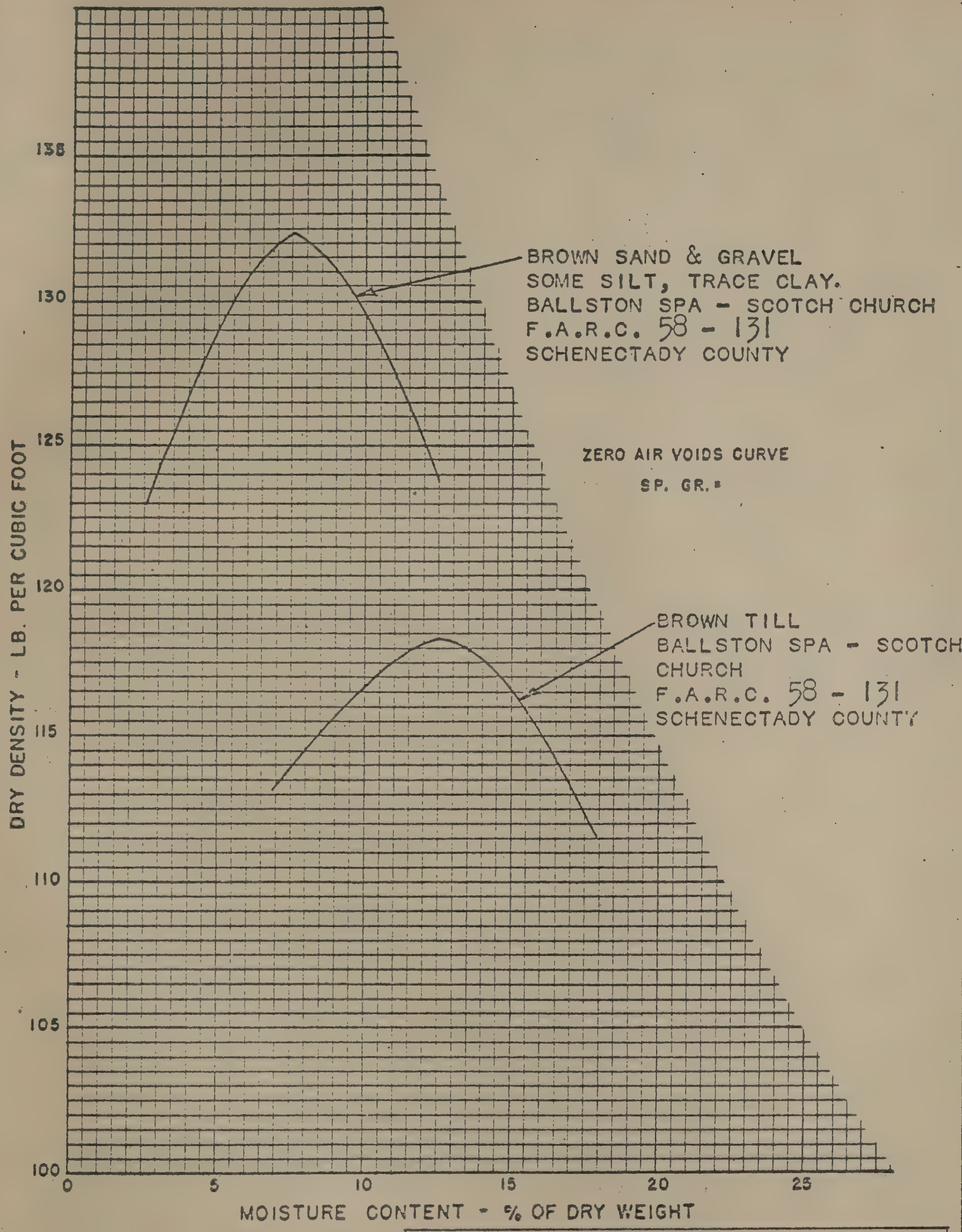


Fig. 1

STATE OF NEW YORK
DEPARTMENT OF PUBLIC WORKS
BUREAU OF SOIL MECHANICS

COMPACTION CONTROL CURVES

FOR MATERIALS IDENTIFIED AS ABOVE

DISTRICT NO. ______ COUNTY ______

DRAWING NO. SM

DRAWN BY: S.M. CHECKED BY: S.M.

APPROVED: OCT. 5, 1959

Wm P. Hofmann

PRINCIPAL SOILS ENGINEER

FORM SM 39B

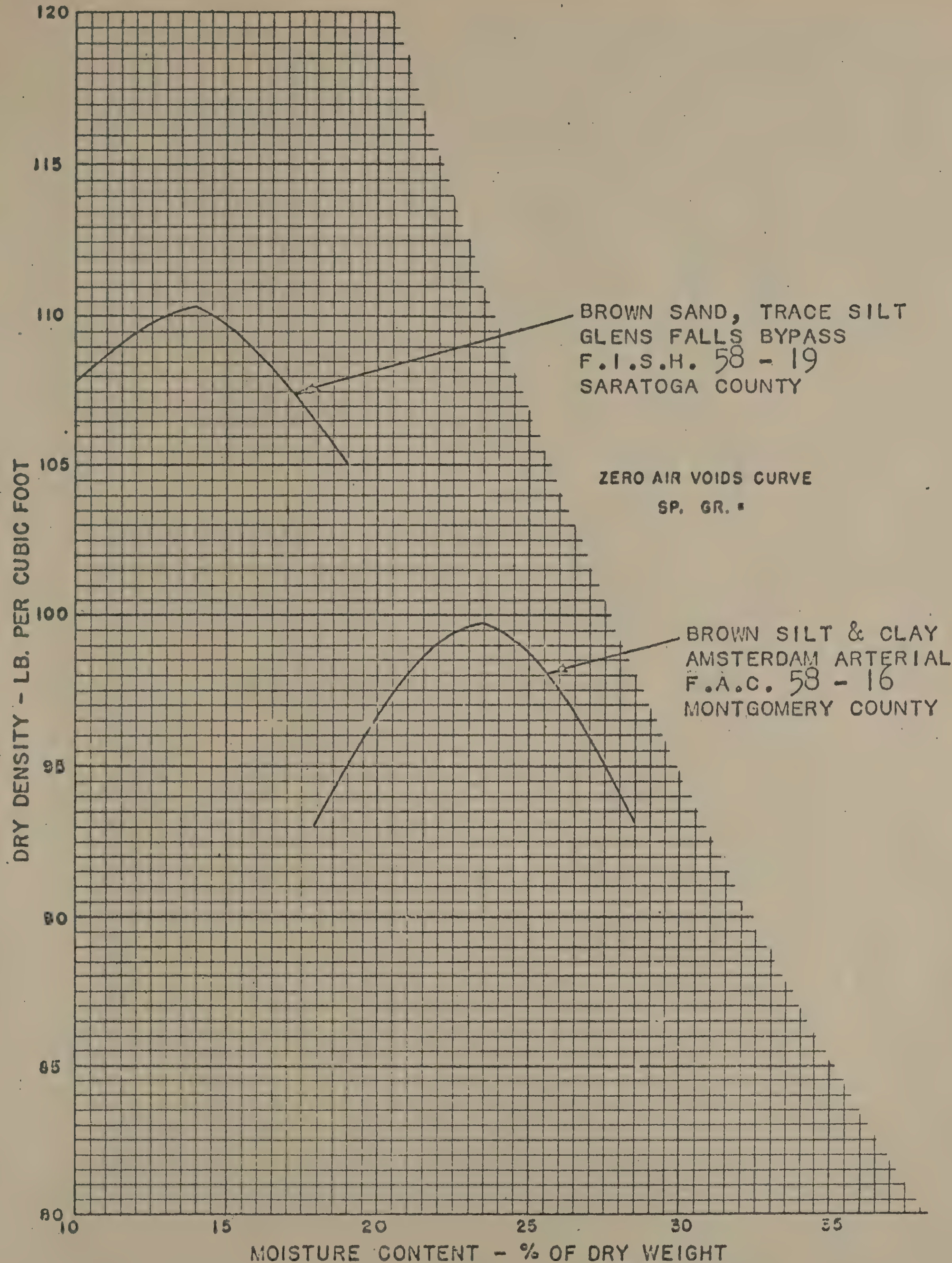


Fig. 2

STATE OF NEW YORK
DEPARTMENT OF PUBLIC WORKS
BUREAU OF SOIL MECHANICS

COMPACTION CONTROL CURVES

FOR MATERIALS IDENTIFIED AS ABOVE

DISTRICT NO.____ COUNTY________

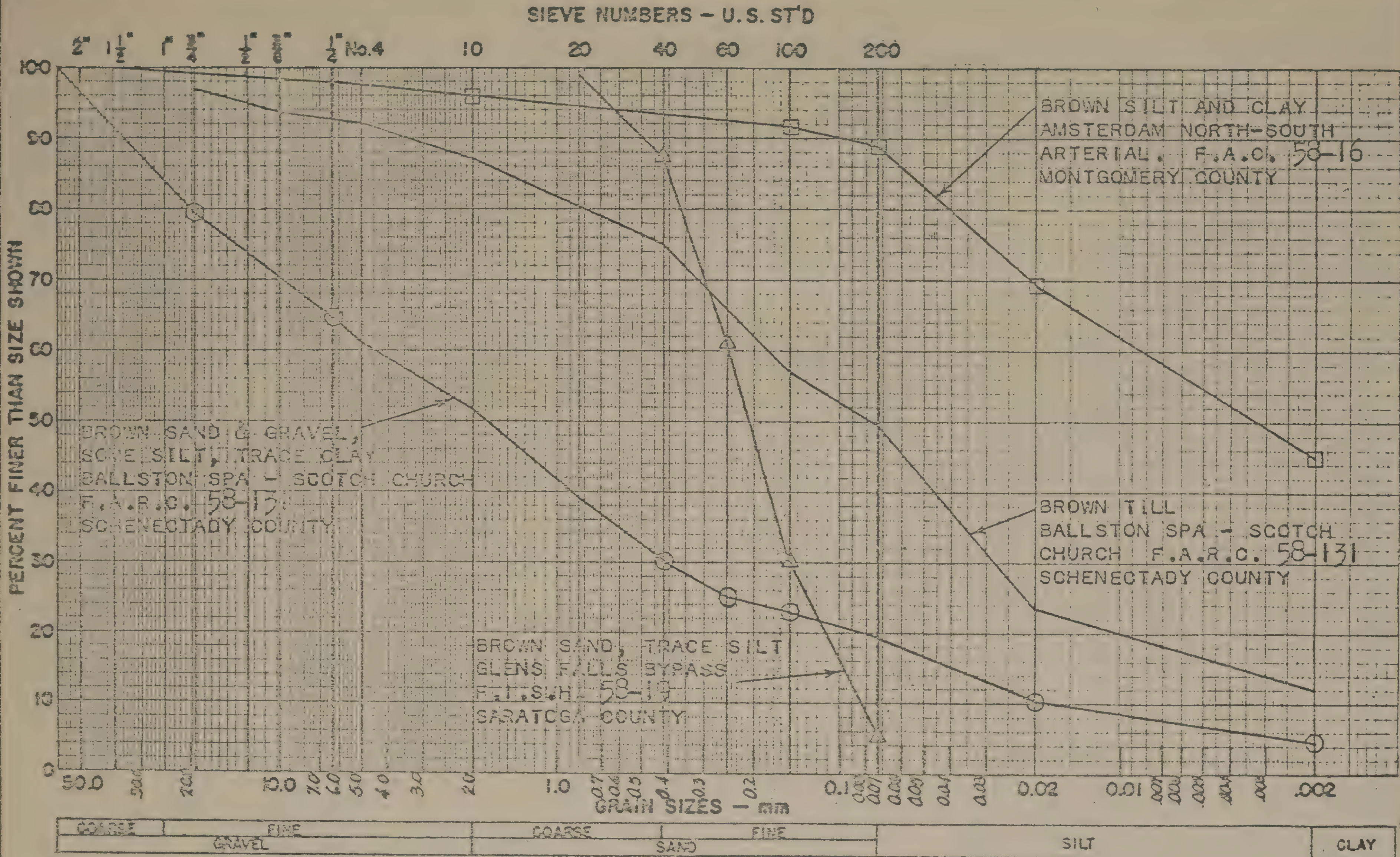
DRAWING NO. SM

DRAWN BY: S.M. CHECKED BY: S.M.

APPROVED: OCT. 5, 1959

Wm. P. Hofmann /sm

PRINCIPAL SOILS ENGINEER



FIELD DENSITY AND MOISTURE CONTENT DETERMINATIONS

PROJECT NUCLEAR CHICAGO D/M GAUGE TESTING EQUIP.-STANDARD SAND

SAMPLE NO. ______ DISTRICT NO. 1 ~~XXXXXX~~ CONE APPARATUS

STATION ______ OFFSET ______ DEPTH ______

DATE OCT. 5, 1959 DRAWN BY S. MINTZER

STATE OF NEW YORK
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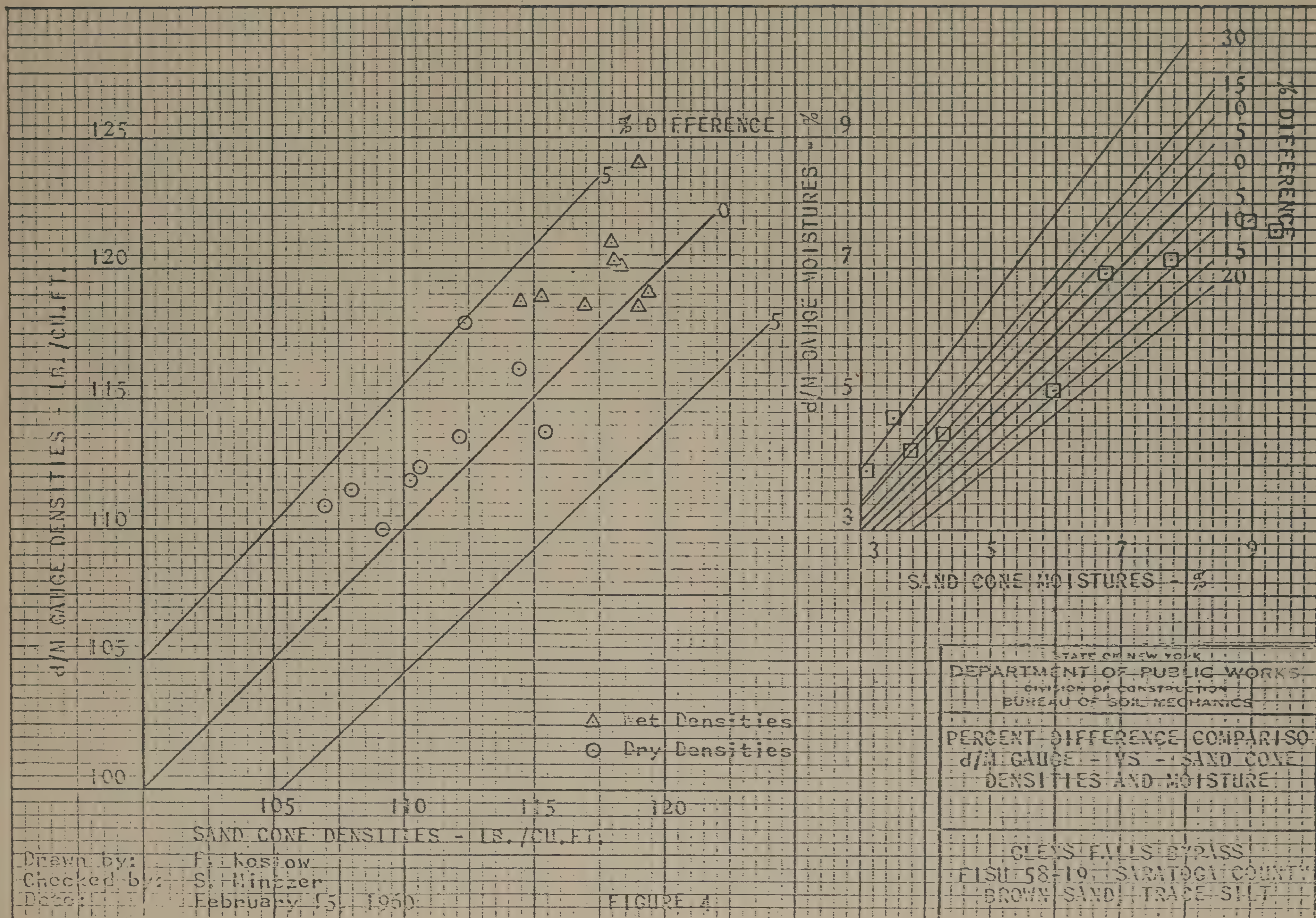
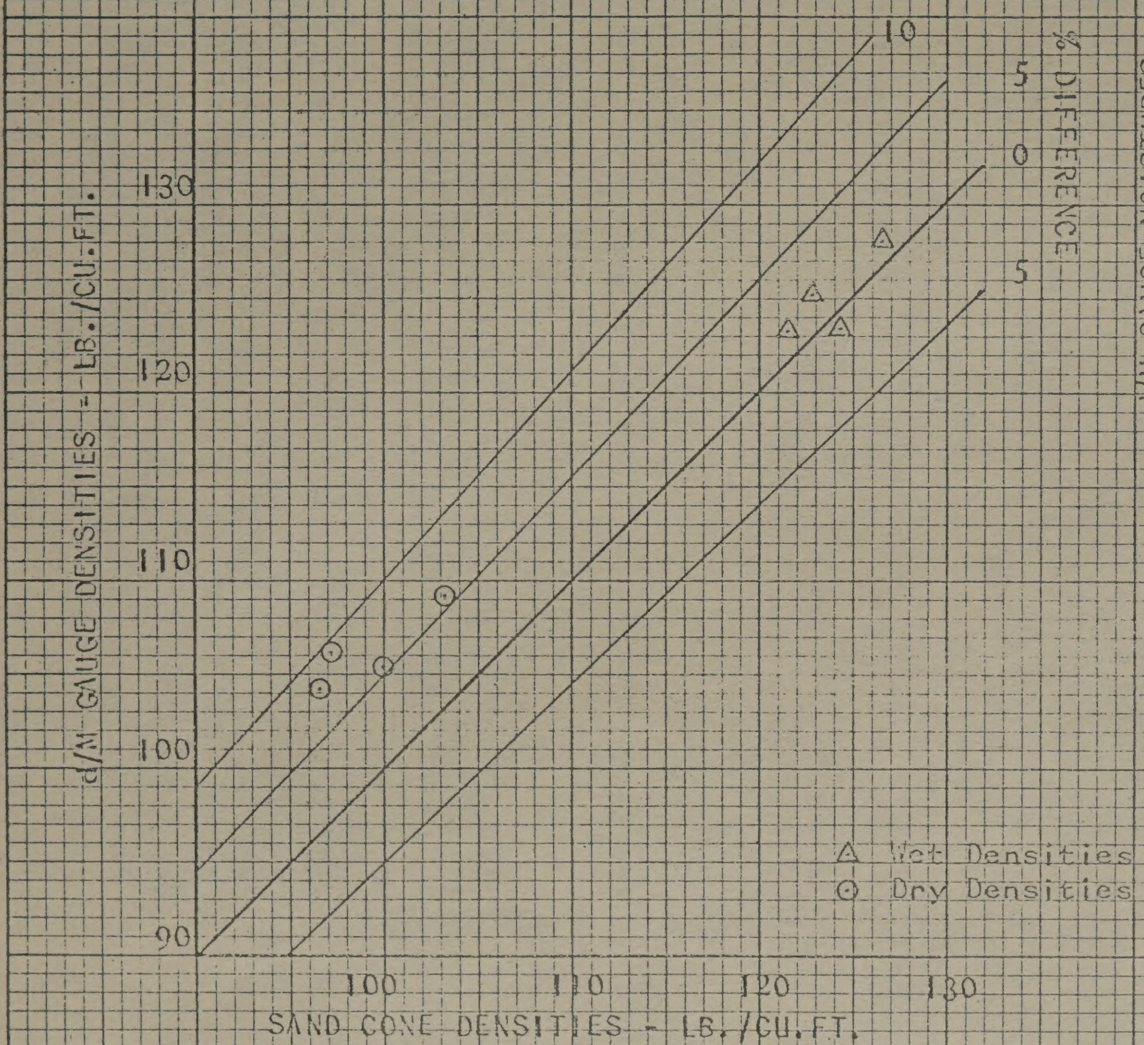
BUREAU OF SOIL MECHANICS
GRAIN SIZE DISTRIBUTION CURVE

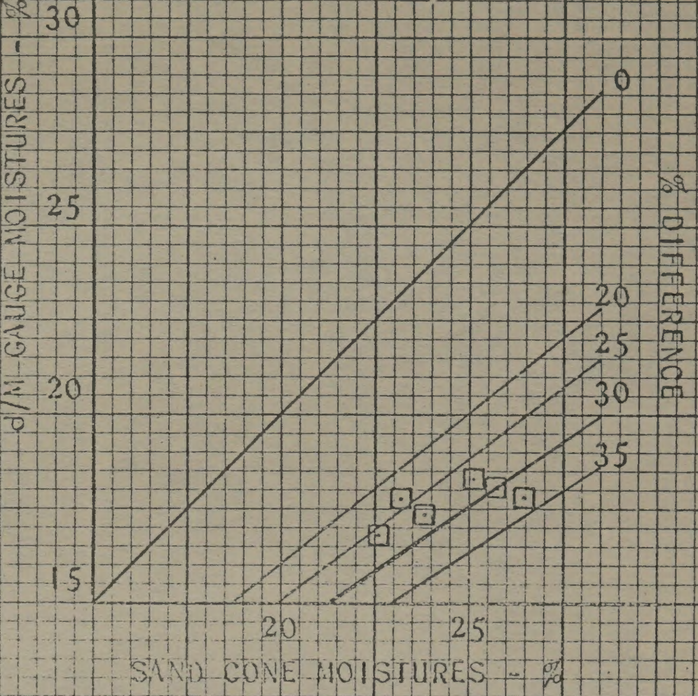
FIG. 3



% DIFFERENCE
5
0
5
△ Wet Densities
⊙ Dry Densities
d/M GAUGE DENSITIES - LB./CU.FT.
125
120
115
110
105
100
105
110
115
120
SAND CONE DENSITIES - LB./CU.FT.
d/M GAUGE MOISTURES - %
9
7
5
3
% DIFFERENCE
30
15
10
5
0
5
10
15
20
3
5
7
9
SAND CONE MOISTURES - %
STATE OF NEW YORK
DEPARTMENT OF PUBLIC WORKS
DIVISION OF CONSTRUCTION
BUREAU OF SOIL MECHANICS
PERCENT DIFFERENCE COMPARISON
d/M GAUGE - VS - SAND CONE
DENSITIES AND MOISTURE
GLENS FALLS BYPASS
FISU 58-19 SARATOGA COUNTY
BROWN SAND - TRACE SILT
Drawn by: F. Kostow
Checked by: S. Minzer
Date: February 15, 1950

FIGURE 4





Drawn by: F. Koslow
Checked by: S. Mintzer
Date: February 15, 1960

FIGURE 5

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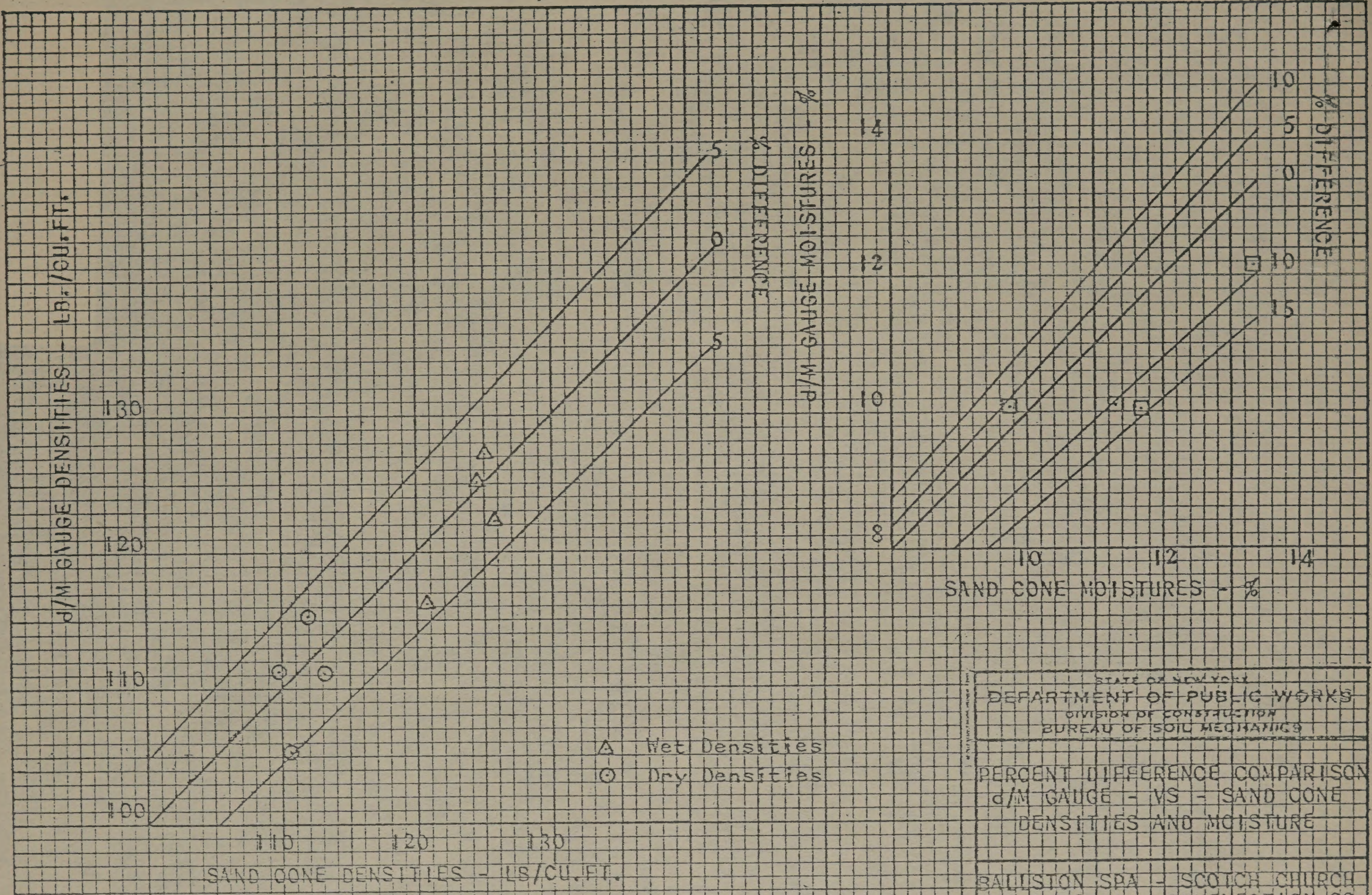
PERCENT DIFFERENCE COMPARISON
d/M GAUGE - VS - SAND CONE
DENSITIES AND MOISTURE

AMSTERDAM ARTERIAL
FAC 58-16 MONTGOMERY CO.
BROWN SILT AND CLAY



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PERCENT DIFFERENCE COMPARISON
d/M GAUGE - VS - SAND CONE
DENSITIES AND MOISTURE

BALLSTON SPA - SCOTCH CHURCH
FARC 58-131 SCHENECTADY CO.
BROWN TILL

Drawn by: F. Koslow
Checked by: S. Mintzer
Date: February 15, 1960

FIGURE 6